Institute of Physics and Engineering in Medicine

Report 91

Recommended Standards for the Routine Performance Testing of Diagnostic X-ray Imaging Systems

CHAPTER 6

Direct digital radiography

Many of the issues with CR systems (Chapter 5) apply to DDR, such as:

- removal of the link between image optical density and exposure;
- DDI;
- correct choice of image processing;
- performing reject analysis;
- use of quantitative analysis and automated QA.

Some of the tests may need adapting for a variety of different technologies used in DDR or may only be required at acceptance. The detector will be integrated into a system with only one x-ray tube serving one or more detectors. At the time of publication, there is little guidance on QA for DDR systems. The tests undertaken and the tolerance levels may need adjusting in line with future evidence and guidance. KCARE has evaluated many digital detectors, these include type testing measurements but also those suitable for routine QA (see MHRA Reports).

Many of the DDR systems have a methodology for calibrating the detector. The person undertaking the QA of the detector should ensure that the previous calibration date is still valid or repeat the calibration, if trained to do so.

The tests described here for AEC devices are used to ensure consistency of the AEC device over the time of its use. The image quality of digital systems is less sensitive to exposure changes than are film/screen systems, and so the AEC device check is more concerned with patient dose than with image quality. The AEC device will generally be supplied with the equipment and so should have been optimised by the manufacturer. However, departments should consider optimising the AEC device independently of the manufacturer. Equipment suppliers and the MPE (as defined in SI, 2000) may be contacted for advice on setting up the AEC device.

Testing of the tube and generator (Chapter 3), workstation and/or laser printer (Chapter 7) must be undertaken before testing the DDR system. When undertaking QA of the tube and generator, it is advisable for most tests to keep the detector out of the beam or protected by lead. Ideally, the tests in Chapter 3 and this chapter should be undertaken consecutively.

Table 6.1 DDR system

Reference paragraph	Physical parameter	Level of expertise	Frequency	Priority	Remedial level	Suspension level
DDR01	Detector dose indicator monitoring	A	1-3 monthly	1	Baseline ±20%[(a)]	Baseline ±50% (a)
DDR02	Image uniformity	A	1-3 monthly	1	Lines or rectangles apparent	Gross non-uniformity
DDR03	Low contrast sensitivity	A	4-6 monthly	2	Baseline ±2 groups	
DDR04	Limiting spatial resolution	A	4-6 monthly	2	Baseline minus 25%	
DDR05	Detector dose indicator repeatability	B	12 monthly	1	Baseline ±10%[(a)]	Baseline ±20% (a)
DDR06	Detector dose indicator reproducibility	B	12 monthly	1	Baseline ±20%[(a)]	Baseline ±50% (a)
DDR07	Measured uniformity	B	12 monthly	1	Mean ±5%	
DDR08	Threshold contrast detail detectability	B	12 monthly	1	See Comments	
DDR09	Limiting spatial resolution	B	12 monthly	2	Baseline minus 25%	
DDR 10	Uniformity of resolution	B	12 monthly	2	Increase in blurring from baseline	
DDR 11	Scaling errors	B	12 monthly	2	>2%	
DDR 12	Dark noise	B	12 monthly	2	Baseline +50%	

* These remedial and suspension levels are based on dosimetry, since the DDI is not linear with exposure.

Table 6.2 AEC device

Reference paragraph	Physical parameter	Level of expertise	Frequency	Priority	Remedial level	Suspension level
DDR 13	Sensitivity	A	1-3 monthly	1	Baseline ±25%	Baseline ±50%
DDR 14	Operation of guard timer	A	12 monthly	1	See Comments	
DDR 15	Consistency between chambers (sensitivity reproducibility)	B	12 monthly	1	Baseline ±30% Mean ±20%	
DDR 16	Repeatability	B	12 monthly	1	Mean ±20%	Mean ±30%
DDR 17	Reproducibility	B	12 monthly	1	Baseline ±30%	Baseline ±60%
DDR 18	Image receptor dose	B	12 monthly	1	Baseline ±30%	Baseline ±60%

6.1 Explanatory paragraphs

DDR01	*Detector dose indicator monitoring*
Suggested method:	70 kV, 3 mA s, 1 mm copper at tube head, 1 m source to image distance (SID), cover the entire detector.
References:	BIR (2001, section K).
Comments:	Record the DDI of the system. The tolerances for the remedial and suspension levels are based on dosimetry; however, the DDI is not necessarily linear with exposure. Medical Physics Expert (MPE) may be required to set appropriate tolerances.

DDR02	*Image uniformity*
Suggested method:	Use image from DDR01. Check image visually.
References:	
Comments:	This is a quick and simple check. A narrow window should be used for viewing the image. Lines or rectangular areas in the image will indicate that recalibration of the detector is required.

DDR03	*Low contrast sensitivity*
Suggested method:	Leeds Test Objects Ltd test object TOR (RAD or CDR), 70 kV, 1 mm copper.
References:	Test object manual.
Comments:	The tolerance is for this test object; for other test objects use a contrast change of 40%. The MPE can give guidance on this and may calculate the number of details from baseline that equate to 40%.

DDR04	*Limiting spatial resolution*
Suggested method:	Lead grating resolution bar pattern, 50 kV, no filtration, at 45° to axis.
References:	Test object manual, BIR (2001, section K), SCAR (2002).
Comments:	The grating may be incorporated in the Leeds Test Objects Ltd test object TOR (RAD or CDR) or other test object.

DDR05	*Detector dose indicator repeatability*
Suggested method:	70 kV, 1.0 mm copper at tube head, at least three times for 10μ*Gy*.
References:	
Comments:	Record the DDI of the system. The tolerance for the remedial and suspension levels are based on dosimetry. However, the DDI is not linear with exposure.

DDR06	*Detector dose indicator reproducibility*
Suggested method:	70 kV, 1.0 mm copper at tube head, at least three exposure levels including 10μGy.
References:	
Comments:	Record the DDI of the system. The tolerances for the remedial and suspension levels are based on dosimetry. However, the DDI may not be linear with exposure. The long-term decline of the system can be monitored. The STPs can be measured using these images by measuring the mean pixel value.

DDR07	*Measured uniformity*
Suggested method:	Use image for 10 μGy from DDR06.
References:	SCAR (2002).
Comments:	Take five ROI over the image, one in the centre of each quadrant and one from the centre of the image. Each ROI should be about 100x100 pixels. Calculate the standard deviation of the five values divided by the mean value. Not all systems will have ROI analysis software. If the pixel value does not have a linear relationship with exposure, the mean values will need to be corrected using the inverse relationship of STR It may be useful to examine the image visually using a narrow window width to look for artefacts. Any system giving results above remedial level should have flat field correction undertaken.

DDR08	*Threshold contrast detail detectability*

Suggested method: Threshold contrast detail test object and appropriate filter and kV.

References: Test object manual; SCAR (2002).

Comments: The filter is normally aluminium or copper and is at the tube head for low scatter conditions. The test conditions need to be established to ensure consistency of measurement.

Comparisons should be made with baseline curves and standard reference curves such as MHRA Reports. According to Gallacher *et al.* (2003), it is possible to base the remedial level on a single figure called the quality index, comparing results with baseline values.

The above describes image quality measurements based on scatter-free conditions. The trend in the USA and other countries is to use phantoms to give more realistic scatter conditions using 20 cm thick PMMA or water in the same position as the patient.

DDR09	*Limiting spatial resolution*

Suggested method: Lead grating resolution bar pattern, 50 kV, no added filtration.

References: Test object manual; SCAR (2002).

Comments: More consistent results are obtained using the test object at 45° compared with the detector. Ensure sufficient exposure to keep the noise low.

DDR10	*Uniformity of resolution*

Suggested method: Fine wire mesh, 50 kV, 10 mA s, SID=1 m, no added filtration.

References: Test object manual, SCAR (2002).

Comments: Check for blurred areas and discontinuities

DDR11	*Scaling errors*

Suggested method: Use grid (e.g. Leeds Test Objects Ltd TO M1), attenuating object of known dimensions or lead ruler.

References:

Comments: This test is used to test the accuracy of the electronic callipers of the systems and to check for non-linearity in the detector, though this test may not be necessary for all types of detector. The distances are measured in the orthogonal directions; use at least 5 cm distance to obtain sufficient accuracy.

This should be repeated on hard copy if a laser printer is used.

DDR12	*Dark noise*

Suggested method: Obtain an image without exposure or with a very low exposure.

References:

Comments: Measure the mean pixel value in a ROI and correct the mean value for the STP. This image can be obtained by directing the tube away from the detector (if possible) or shielding the detector and using very low exposure factors. This test is useful for testing that the noise in the system is not excessive. Also, the image should be examined for significant structural noise.

DDR13	*Sensitivity*

Suggested method: Use 70 kV, 1 mm copper in beam (or other suitable phantom), expose under AEC device control, irradiate whole detector. Record the mAs and DDI reading.

References:

Comments: This is a simple quick check that the AEC device is functioning correctly. Comparison should be made with the baseline mAs figures. In the event of the suspension level being exceeded, it may be possible to defer suspension from clinical use by adjusting the default AEC device density offset.

DDR14	*Operation of guard timer*
Suggested method:	Check the exposure time, using a low kV, with lead blocking the AEC chambers or, if possible, direct the beam away from the AEC chambers while ensuring that the beam is appropriately attenuated.
References:	
Comments:	Check that the AEC device terminates the exposure at the guard timer setting or, preferably, that the exposure is terminated quickly when the system calculates that the guard time will be exceeded.

DDR15	*Consistency between chambers*
Suggested method:	Suitable attenuation material, e.g. PMMA, water or water equivalent slabs.
References:	IPEMB (1997b, Report 32 part IV).
Comments:	The consistency should be checked for each chamber and for various combinations of chambers on a single AEC system. Record the mAs and the DDI. The DDI may need to be converted into an exposure measurement. Comparison should also be made between AEC devices where there is more than one in a room.

DDR16	*Repeatability*
Suggested method:	Suitable attenuation material, e.g. PMMA, water or water equivalent slabs. Irradiate whole phantom.
References:	IPEM (1997b, Report 32 part IV section 2.5).
Comments:	Record the mAs and the DDI. The purpose of this test is to ensure that the recorded DDI is consistent between successive repeated exposures using the same AEC device settings.

DDR17	*Reproducibility*
Suggested method:	Suitable attenuation material, e.g. PMMA, water or water equivalent slabs.
References:	IPEM (1997b, Report 32 part IV section 2.5).
Comments:	Record the mAs and the DDI reading. This test is similar to DDR 15 but is more extensive, covering a suitable range of kV and thickness of phantoms.

DDR18	*Image receptor dose*
Suggested method:	Dosemeter in front of digital detector measure without grid and without backscatter. 1.0 mm copper at tube head.
References:	
Comments:	The Guidance Notes (IPEM, 2002 para. 3.32) require the air kerma at the image receptor to be evaluated at the various control settings. It would be reasonable to evaluate the dose at a few commonly used settings so long as the resultant mAs is recorded for the remainder, so that a good estimate of the dose may be inferred. The dosemeter should have a calibration traceable to an appropriate primary standard. The receptor dose can be made with PMMA or water equivalent slabs. However, a measurement or estimation has to be made about the primary beam attenuated by the grid and the scatter removed from the beam.

CHAPTER 7

Image display and hardcopy devices

An addition to this edition of IPEM Report 77 is a series of tests to be performed on the image viewing and hardcopy process, including film viewers, display monitors and ambient lighting conditions. These are essential components of any QA programme, since inadequacies in this area may serve to negate the benefits of efforts to maintain quality and consistency in other elements of the imaging process.

The modern radiology department requires digital images from a number of different equipment modalities to be viewed in a variety of locations by different individuals. Further, a PACS (picture archive and communication system) can mean that the medical images are available to clinicians throughout the hospital and beyond. The need to carry out regular testing of such equipment has been highlighted by such bodies as the RCR (2002, 2004) and the Medicines and Healthcare products Regulatory Agency (MHRA, 2004).

The MHRA defines two classes of display, namely diagnostic and review, and the requirements for such softcopy displays will depend on which class of device is being considered. Similarly, in accordance with the guidelines set down by the American College of Radiology (ACR, 2003), display devices for medical imaging are characterised as either Primary or Secondary. Primary display systems are those systems used for the interpretation of medical images. Secondary systems are those used for viewing medical images for purposes other than for providing a medical interpretation. They are usually used for viewing images by general medical staff and medical specialists other than radiologists, and utilised after an interpretative report is provided for the images. Secondary systems also include operators' console monitors and QC workstations, display devices that are commonly used to adjust the images before they are sent to PACS or hardcopy printers. As the performance of these systems (especially their luminance response) directly affects image presentation at other display devices, their performance needs to maintain a minimum level of acceptability, and thus they are treated as Secondary class displays.

The action levels contained within this report address QA for the 'Primary' display (medical device for diagnosis), since it is essential that these monitors are performing optimally. However, although Secondary displays do not require the same level of image QA as diagnostic displays, they still need to be cleaned and the image quality maintained (MHRA, 2004). Special consideration may need to be given to monitors used for medical management decisions.

Both flat-panel monitors and cathode ray tubes (CRTs) are known to degrade over time, therefore requiring routine monitoring (MHRA, 2004; AAPM, 2005).

A number of tests refer to using test images such as the Society of Motion Picture and Television Engineers (SMPTE) test pattern or those recommended by the American Association of Physicists in Medicine (AAPM, 2005), which can be downloaded from: http://deckard.mc.duke.edu/-samei/tgl8 or www.aapm.org/pubs/reports

The performance monitoring of film digitisers used to digitise clinical images for archive and image transfer purposes is not addressed here. Interested readers are referred to Verdun *et al.* (2000) and Meeder *etal.(* 1995).

Table 7.1 Film viewer

Reference paragraph	Physical parameter	Level of expertise	Frequency	Priority	Remedial level
IDD01	Film viewer condition	A	6 monthly	1	See Comments
IDD02	Film viewer luminance	B	6-12 monthly	1	<1500 or >3000 cd
IDD03	Film viewer uniformity	B	6-12 monthly	1	>20%
IDD04	Film viewer variation	B	6-12 monthly	2	>±20% difference from mean value within a bank
IDD05	Room illumination	B	6-12 monthly	2	>100 lux (general radiography) >50 lux (mammography)

Table 7.2 Image display monitor

Reference paragraph	Physical parameter	Level of expertise	Frequency	Priority	Remedial level
IDD06	Image display monitor condition	A	Daily to weekly	1	See Comments
IDD07	Greyscale	A	3 monthly	1	Ratio white to black <250
IDD08	Distance and angle calibration	A	3 monthly	1	±5 mm ±3°
IDD09	Resolution	A	3 monthly	1	See Comments
IDD10	Greyscale	B	6-12 monthly	1	Black baseline ±25% White baseline ±20%
IDD11	DICOM greyscale calibration	B	6-12 monthly	1	GSDF ±10%
IDD12	Uniformity	B	6-12 monthly	1	>30%
IDD13	Variation between monitors	B	6-12 monthly	1	>30%
IDD14	Room illumination	B	6-12 monthly	1	>15 lux

Table 7.3 Hardcopy device

Reference paragraph	Physical parameter	Level of expertise	Frequency	Priority	Remedial level
IDD15	Sellf-calibration	A	Daily to weekly	1	Manufacturer's specification
IDD16	Optical density consistency	A	3 monthly	1	Baseline OD ±0.20
IDD17	Image quality	A	3 monthly	1	Based on visual inspection

7.1 Explanatory paragraphs

IDD01	*Film viewer condition*

Suggested method: Visual inspection and appropriate cleaning materials.

References: BIR (2001, section Ml); IPEMB (1996, Report 32 part IV. section 1.3); McCarthy and Brennan (2003).

Comments: Film viewers (light boxes) should be clean, uniformly illuminated and the perceived brightness and colours of illumination should be consistent within a bank of illuminators. Faulty bulbs should be replaced as soon as they are identified.

It has been reported (McCarthy and Brennan, 2003) that, following cleaning, 80% of film viewers tested demonstrated improved luminance uniformity.

IDD02	*Film viewer luminance*

Suggested method: Photometer (measuring in cd m^{-2}).

References: BIR (2001, section Ml); Hartmann and Stieve (1989).

Comments: The purpose of this test is to ensure that all film viewers are operating at an appropriate luminance level.

The photometer should comply with the CIE standard photopic spectral response (AAPM, 2005) and have a calibration traceable to an appropriate primary standard.

IDD03	*Film viewer uniformity*

Suggested method: Photometer (measuring in cd m^{-2}).

References: BIR (2001, section M2); McCarthy and Brennan (2003).

Comments: This test comprises a check on the uniformity of luminance over the surface of each film viewer. The luminance is measured at the centre and periphery of the film viewer and the maximum (L_{max}) and minimum (L_{min}) values used to calculate the percentage uniformity *U(%)* using the following formula:

$$U(\%) = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} X\, 200$$

IDD04	*Film viewer variation*
Suggested method:	Photometer (measuring in cdm^{-2}).
References:	BIR (2001, section M3); Hartmann and Stieve (1989).
Comments:	The luminance in the centre of each film viewer should be compared to establish that the variation between viewers is within acceptable limits.

IDD05	*Room illumination*
Suggested method:	Photometer (measuring in lux).
References:	Hartmann and Stieve (1989); McCarthy and Brennan (2003).
Comments:	The film viewers in the viewing area should be switched off and, under otherwise normal viewing conditions, the ambient light level should be evaluated in the normal viewing position. The mammography remedial level is based on MDA/98/57 (MDA, 1998b).

IDD06	*Image display monitor condition*
Suggested method:	Visual inspection of test pattern image such as SMPTE or TG18-QC and appropriate cleaning materials.
References:	AAPM (2005).
Comments:	Image display monitors should be clean, and the perceived contrast of the test pattern should be consistent between monitors connected to the same workstation (RCR, 2002). Ensure that the 5% and 95% details superimposed on the 0% and 100% squares, respectively, are visible.

IDD07	*Greyscale*
Suggested method:	Photometer and test pattern image such as SMPTE or TG18-QC.
References:	AAPM (2005); IEC (1994b).
Comments:	Measure luminance of black (0%) and white (100%) squares.

IDD08	*Distance and angle calibration*
Suggested method:	Measure fixed distance and angle on a regular test pattern image.
References:	
Comments:	This test is intended for those applications where measurements of distance and angle are performed using the image display monitor and diagnostic workstation (RCR, 2002).

IDD09	*Resolution*
Suggested method:	Visual inspection of test pattern image such as SMPTE or TG18-QC.
References:	AAPM (2005).
Comments:	Review both low contrast and high contrast resolution patterns. Check resolution at centre and periphery is consistent and similar to baseline image.

IDD10	*Greyscale*
Suggested method:	Photometer and test pattern image such as SMPTE or TG18-QC.
References:	AAPM (2005); IEC (1994b).
Comments:	Measure luminance of black (0%) and white (100%) squares with calibrated photometer. The photometer should comply with the CIE standard photopic spectral response (AAPM, 2005) and have a calibration traceable to an appropriate primary standard.

IDD11	*DICOM greyscale calibration*
Suggested method:	Photometer and test pattern images such as TG18-LN (test patterns 1 to 18), SMPTE or TG18-QC
References:	AAPM (2005).

Comments: This test involves measuring a number of luminance levels, computing the contrast between consecutive levels and comparing them with the DICOM Greyscale Standard Display Function (GSDF). The measured contrast response at any given point should fall within ±10% of the standard. In order to relate measured luminance values to the DICOM standard luminance response, the p-values (depending on bit-depth) used in the measurements of luminance need to be transformed to just-noticeable-difference (JND) indices (AAPM, 2005). It is important to note that, for some display devices, the contrast response may vary as a function of viewing angle. AAPM (2005) suggest that the variation is very small for CRT devices, but AMLCD devices may exhibit significant variations, depending on the design of the pixel elements.

The photometer should comply with the CIE standard photopic spectral response (AAPM, 2005) and have a calibration traceable to an appropriate primary standard.

IDD12	*Uniformity*

Suggested method: Photometer and test pattern image such as SMPTE or TG18-QC.

References: AAPM (2005).

Comments: Measure luminance of 50% level at centre and four corners of screen. The maximum(Lmax)and minimum(Lmin)values

used to calculate the percentage uniformity U(%) using the following formula:

$$U(\%) = \frac{L_{\max} - L_{\min}}{L_{\max} + L_{\min}} X\, 200$$

IDD13	*Variation between monitors*

Suggested method: Photometer and test pattern image such as SMPTE or TG18-QC, TG18-CT, TG18-UN.

References: AAPM(2005).

Comments: This is to compare the consistency of greyscale range between multiple monitors on the same workstation and between monitors on different workstations (RCR, 2002). Measure luminance of black (0%) and white (100%) level on each monitor.

1DD14	*Room illumination*

Suggested method: Photometer (measuring in lux).

References: Chakrabarti *et al.* (2003); AAPM (2005).

Comments: The display monitor should be switched off and, under otherwise normal viewing conditions, the ambient light level should be evaluated in the normal viewing position. See also MHRA (2004).

IDD15	*Self-calibration*

Suggested method: Run built-in auto calibration facility.

References: BIR (2001, section N1).

Comments: This is to monitor the systems reproducibility in optical density over a range of densities.

IDD16	*Hardcopy device optical density consistency*

Suggested method: Print greyscale step wedge and measure densities.

References: BIR (2001, section N2); IEC(1994a).

Comments: This is to check the calibration of the laser imager. Remedial level is based on a baseline value of 1.0±0.15 optical density (IEC, 1994a)

IDD17	*Hardcopy device Image quality*

Suggested method: Print standard test image and perform visual inspection.

References: BIR (2001, section N3).

Comments: